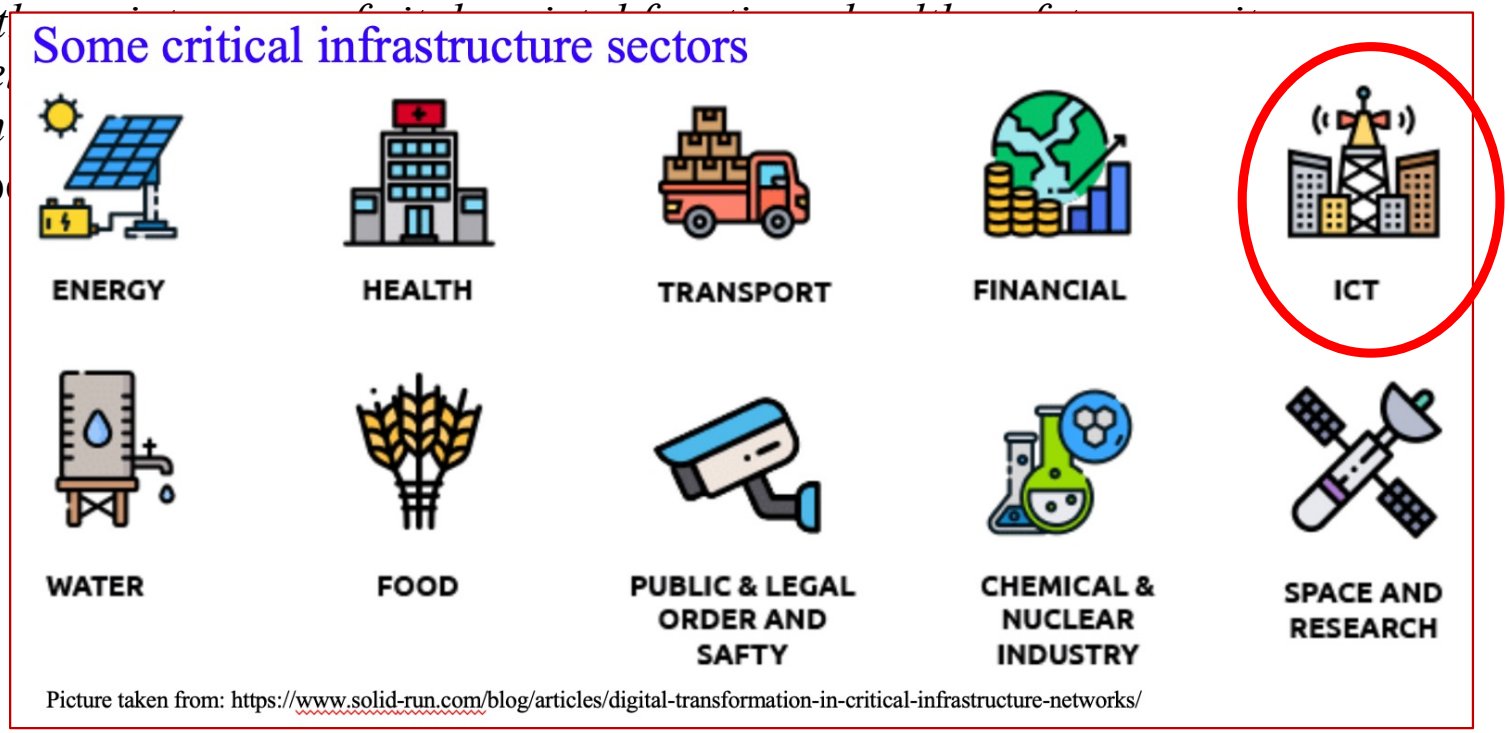
Resilience Benchmarking of Critical Infrastructures

Henrique Madeira
University of Coimbra, Portugal

University of Coimbra

Critical Infrastructures (CI)

- **A Critical Infrastructure is** *"an asset, system or part thereof located in Member States which is essential for t… economic or social we… a significant impact in…*
  Council of the Europ…

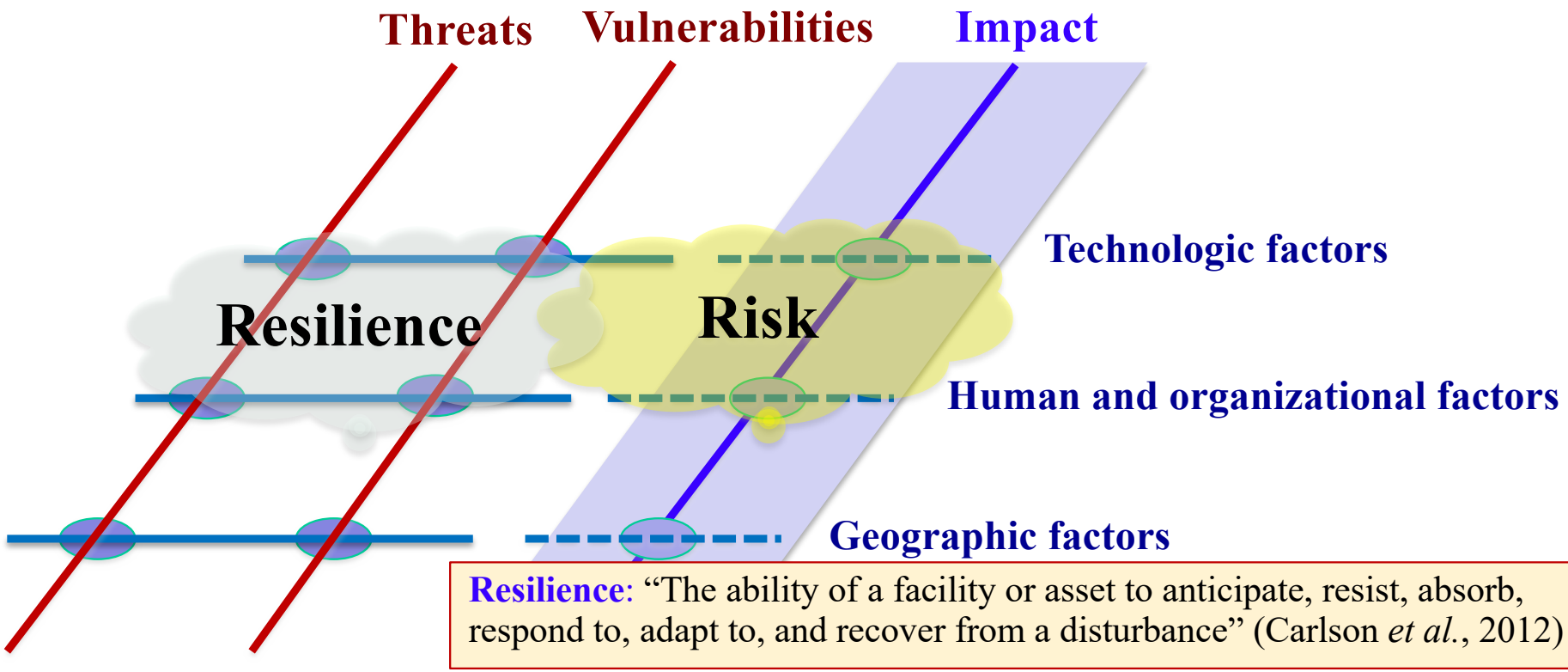


Critical Infrastructures (CI)

- **A Critical Infrastructure is** *"an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions"*, **Council of the European Union**, 2008.

- **Critical infrastructures:**
  - Encompass public and private sectors and society at large
  - Nearly unbounded (critical information infrastructures – **CII** are effectively unbounded)
  - Complex
  - Networked
  - Cyber-physical
  - Highly human dependent
  - **Vulnerable** **… but modern society depends on them**

Threats, Vulnerabilities, Impact, and Risk



Resilience: "The ability of a facility or asset to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance" (Carlson *et al.*, 2012)

Risk: "*the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences*" (Department of Homeland Security, 2010)

Critical Infrastructure Protection

- Two facets of the BIG problem:

  a) **How to protect CIs?**

  b) **How to be sure that CIs are in fact protected?**

Henrique Madeira, DEI-FCTUC, 2021

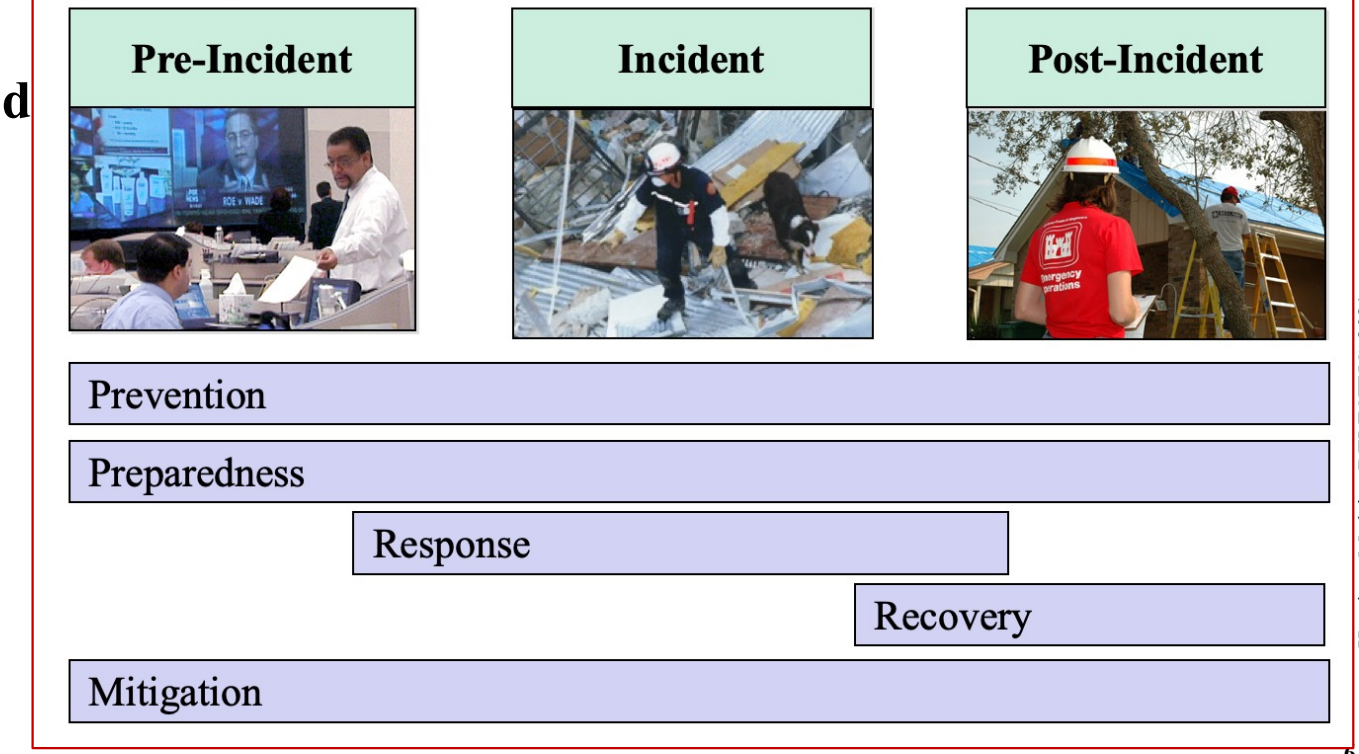
Critical Infrastructure Protection

- Two facets of the BIG problem:

  a) **How to protect CIs?**

  b) **How to be sure that CIs are in fact protected**

Example: Incident Management according to NIPP (National Infrastructure Protection Plan), USA



Critical Infrastructure Protection

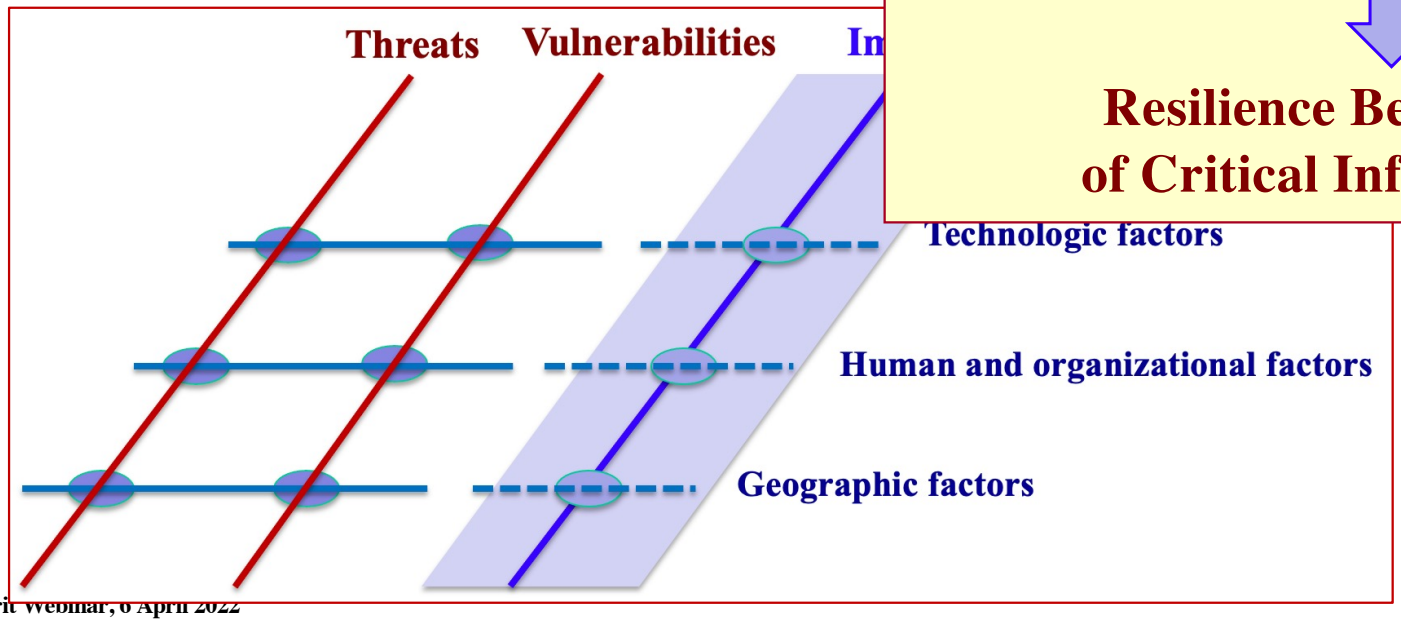
- Two facets of the BIG problem:

  a) **How to protect CIs?**

  b) **How to be sure that CIs are in fact protected?**

How to evaluate resilience of CIIs and associated physical CIs?

Resilience Benchmarking of Critical Infrastructures



Measuring, assessing, and benchmarking

A single word is not enough…

Measuring, **assessing**, and **benchmarking** … resilience

Measuring

The act of obtaining a proper measurement for a parameter or metric. It relies on a **quantitative** with well-known scale/reference.

Measurement uncertainty can make the difference between good and bad measurements.

Quality of measurements is all about uncertainty evaluation.

Henrique Madeira, DEI-FCTUC, 2021

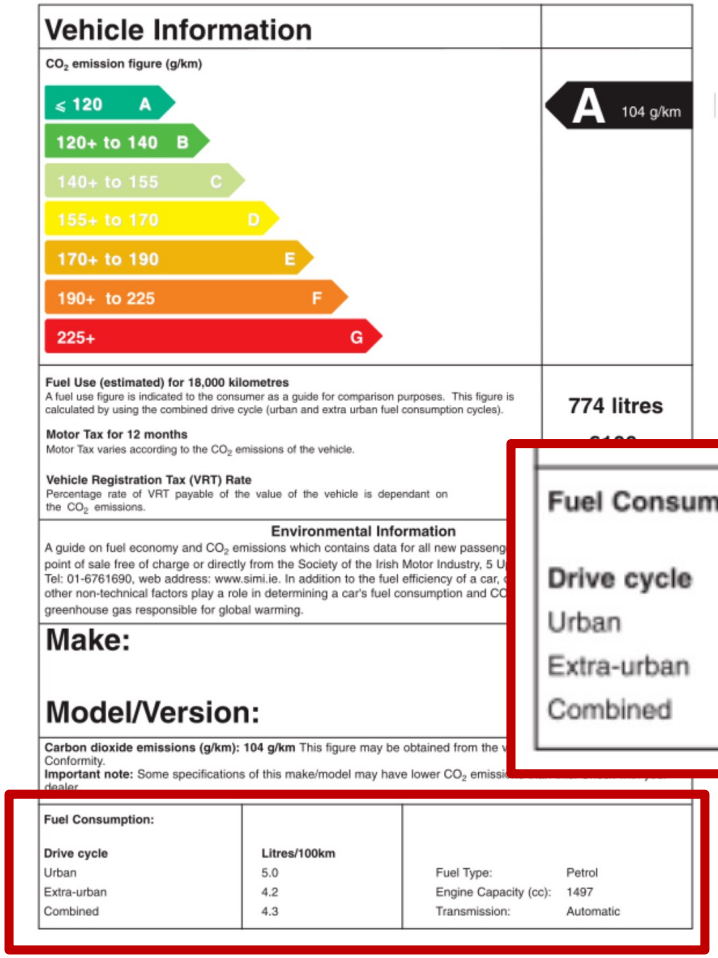
Assessing

The act of classifying something with respect to its worth. It can just be **qualitative**.

Benchmarking

Agreement/contract and well-identified properties to ensure fairness in **comparison** *(DBench project)*.

Benchmarking



Vehicle Information

CO_2 emission figure (g/km)

≤ 120 A
120+ to 140 B
140+ to 155 C
155+ to 170 D
170+ to 190 E
190+ to 225 F
225+ G

A 104 g/km

Fuel Use (estimated) for 18,000 kilometres
A fuel use figure is indicated to the consumer as a guide for comparison purposes. This figure is calculated by using the combined drive cycle (urban and extra urban fuel consumption cycles).

774 litres

Motor Tax for 12 months
Motor Tax varies according to the CO_2 emissions of the vehicle.

Vehicle Registration Tax (VRT) Rate
Percentage rate of VRT payable of the value of the vehicle is dependant on the CO_2 emissions.

Environmental Information
A guide on fuel economy and CO_2 emissions which contains data for all new passeng
point of sale free of charge or directly from the Society of the Irish Motor Industry, 5 U
Tel: 01-6761690, web address: www.simi.ie. In addition to the fuel efficiency of a car,
other non-technical factors play a role in determining a car's fuel consumption and C
greenhouse gas responsible for global warming.

Make:

Model/Version:

Carbon dioxide emissions (g/km): 104 g/km This figure may be obtained from the
Conformity.
Important note: Some specifications of this make/model may have lower CO_2 emissi
dealer.

Fuel Consumption:

Drive cycle	Litres/100km
Urban	5.0
Extra-urban	4.2
Combined	4.3

Fuel Type:	Petrol
Engine Capacity (cc):	1497
Transmission:	Automatic

Agreement/contract and well-identified properties to ensure fairness in **comparison** *(DBench project)*.

Fuel Consumption:

Drive cycle	Litres/100km
Urban	5.0
Extra-urban	4.2
Combined	4.3

Fuel Type:	Petrol
Engine Capacity (cc):	1497
Transmission:	Automatic

Critical Information Infrastructures (CII)

- CII: systems, services, networks and ICT infrastructures
  - CII are Critical Infrastructures for themselves (e.g., in sectors such as communications, finance, etc.)
  - CII underpins nearly all physical infrastructures creating complex and interconnected cyber-physical systems (and systems of systems)
  - CII are essential to protect physical critical infrastructures, to monitor them… but also create **vulnerabilities** and greatly increase the **attack surface**
- Resilience assessment and resilience benchmarking of CI is largely a problem of **dependability assessment of computer systems.**

Computer system dependability

Computer system dependability is defined as *"the **trustworthiness** of a computing system which allows reliance to be justifiably placed on the service it delivers", IFIP 10.4*

Terminology is a slippery terrain…

Henrique Madeira, DEI-FCTUC, 2021

Trustworthiness

- Trustworthy CII should be:
  - Secure
  - Dependable
  - Resilient

  to attacks, operational faults and changes

Their measurement require different metrics, methods and tools

Quite different types of "entities"…

Henrique Madeira, DEI-FCTUC, 2021

Measuring trustworthiness

- Trustworthy CII should be:
  - Secure
  - Dependable
  - Resilient

  to attacks, operational faults and changes

Measuring, assessing and benchmarking security is even harder

Measuring, assessing, and benchmarking dependability and resilience (in a practical and affordable way) is far from being solved…

Proposal: find practical ways to benchmark resilience of CIIs and CIs

Computer benchmarks…

- Standardized (*de facto*) methods and tools to compare (and rank) different systems or components according to specific characteristics (metrics)
  - e.g., performance, robustness, dependability, etc.
- Originally focused on performance
  - Transaction Processing Performance Council (TPC)
  - Standard Performance Evaluation Corporation (SPEC)
  - Specific benchmarks from system vendors
- Dependability and security have been proposed in the last two decades... But have not really adopted by industry and user communities in the same way performance benchmark had.

Some key features of computer benchmarks

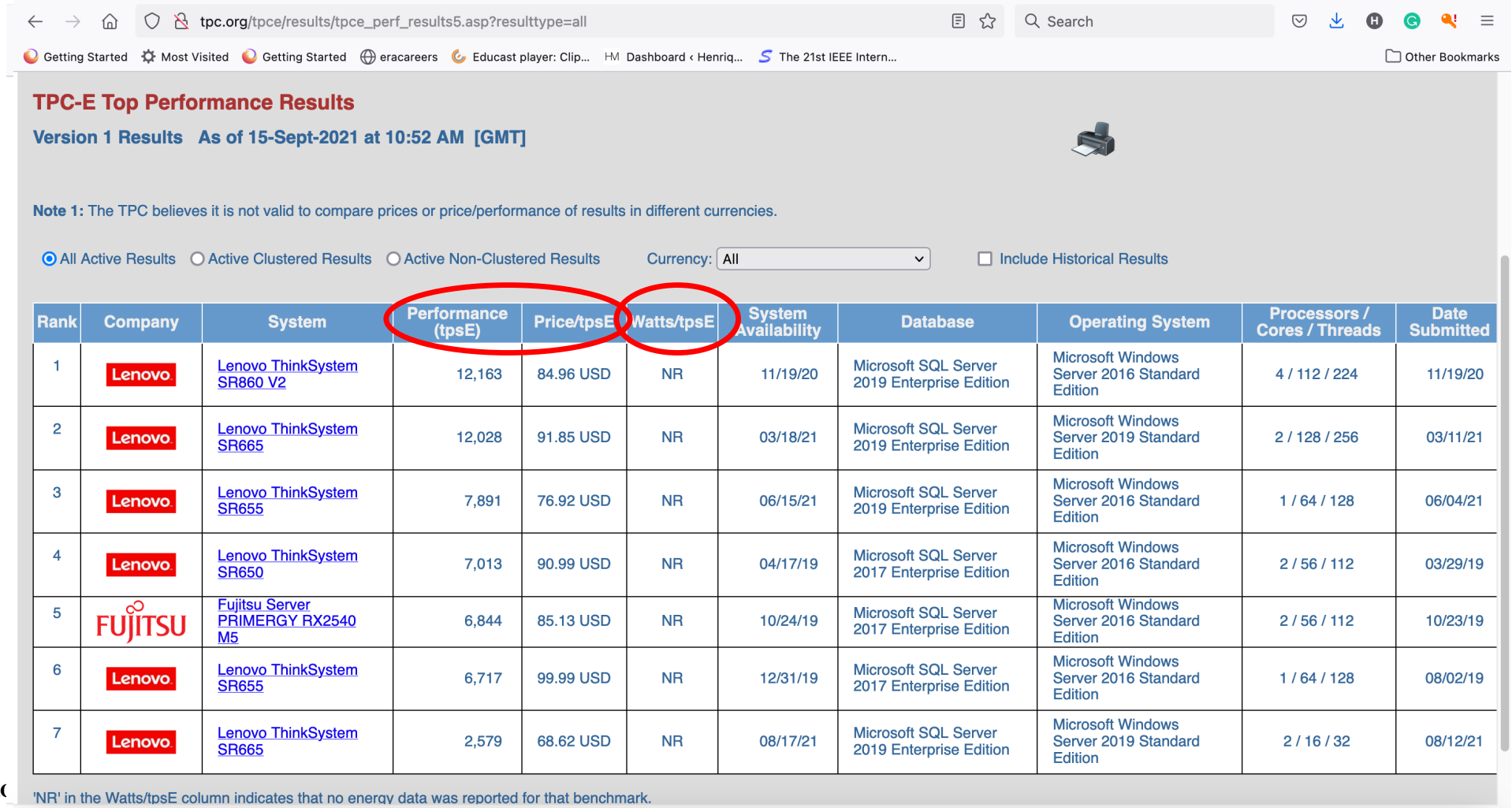
- **Simplicity** (easy to understand)
- **Small number of metrics** (to allow easy comparison)
- **Fairness** (to allow correct comparisons)
- **Usefulness** (to promote improvement of system features)
- **Representativeness** (enough to be useful, while keeping simplicity)
- **Highly specific** (of a domain or type of target systems)

A benchmarks is an agreement (explicit or tacit) among stakeholders (vendors, users, policy makers,…)

Examples of organizations and websites proposing and managing benchmarks

- TPC or Transaction Processing Council
- SPEC or Standard Processing Evaluation Corporation
- RPE2 by Gartner (Previously Ideas International)
- SAPS by SAP as part of the SAP Standard Application Benchmark
- SPE (Systems Performance Engineering)
- …

TPC Benchmarks (example)



TPC-E Top Performance Results

Version 1 Results As of 15-Sept-2021 at 10:52 AM [GMT]

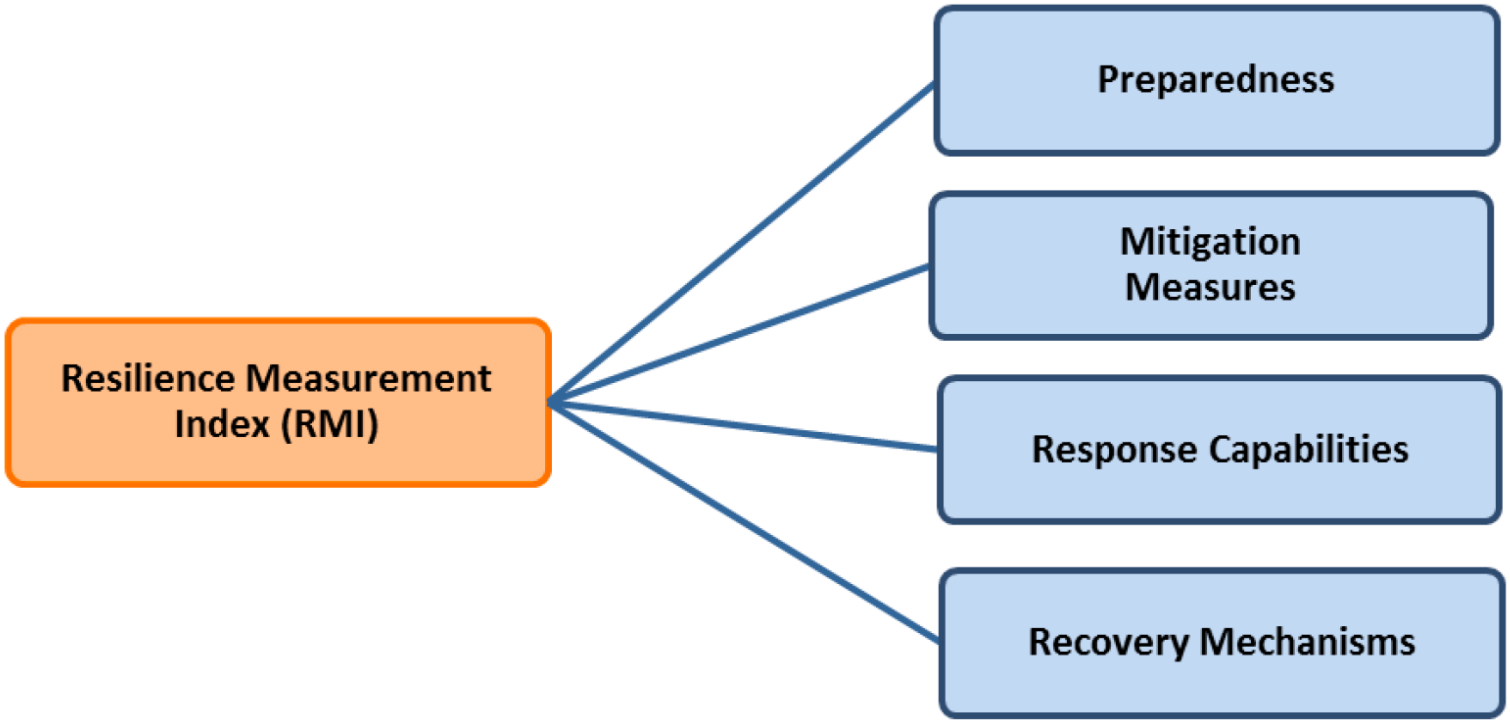
Note 1: The TPC believes it is not valid to compare prices or price/performance of results in different currencies.

All Active Results | Active Clustered Results | Active Non-Clustered Results | Currency: All | Include Historical Results

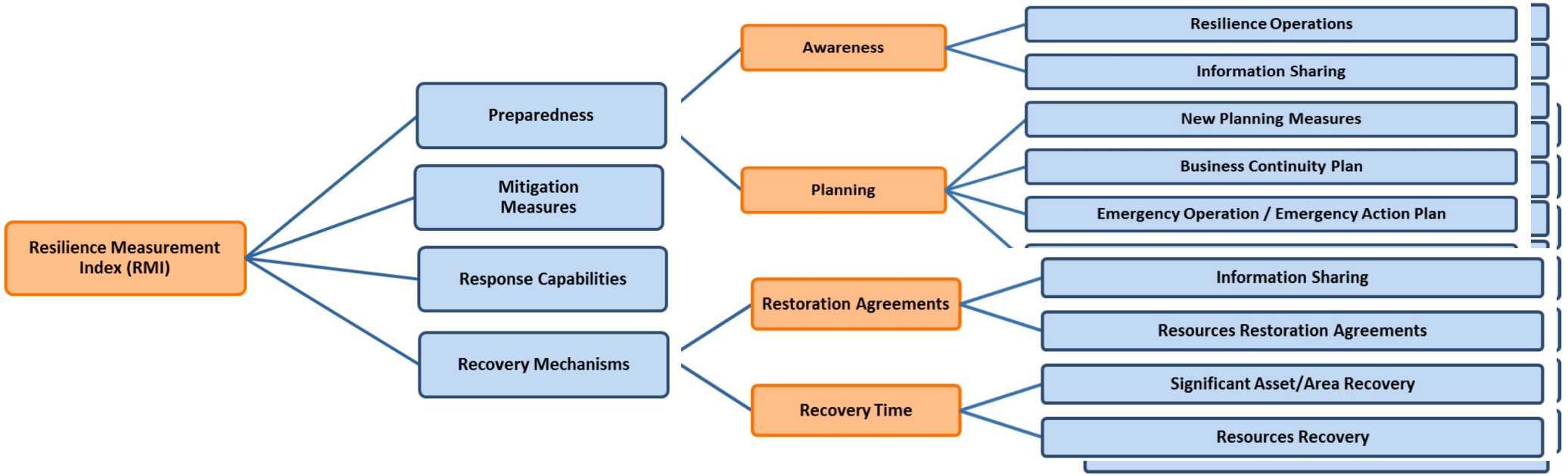
Rank	Company	System	Performance (tpsE)	Price/tpsE	Watts/tpsE	System Availability	Database	Operating System	Processors / Cores / Threads	Date Submitted
1	Lenovo	Lenovo ThinkSystem SR860 V2	12,163	84.96 USD	NR	11/19/20	Microsoft SQL Server 2019 Enterprise Edition	Microsoft Windows Server 2016 Standard Edition	4 / 112 / 224	11/19/20
2	Lenovo	Lenovo ThinkSystem SR665	12,028	91.85 USD	NR	03/18/21	Microsoft SQL Server 2019 Enterprise Edition	Microsoft Windows Server 2019 Standard Edition	2 / 128 / 256	03/11/21
3	Lenovo	Lenovo ThinkSystem SR655	7,891	76.92 USD	NR	06/15/21	Microsoft SQL Server 2019 Enterprise Edition	Microsoft Windows Server 2016 Standard Edition	1 / 64 / 128	06/04/21
4	Lenovo	Lenovo ThinkSystem SR650	7,013	90.99 USD	NR	04/17/19	Microsoft SQL Server 2017 Enterprise Edition	Microsoft Windows Server 2016 Standard Edition	2 / 56 / 112	03/29/19
5	FUJITSU	Fujitsu Server PRIMERGY RX2540 M5	6,844	85.13 USD	NR	10/24/19	Microsoft SQL Server 2017 Enterprise Edition	Microsoft Windows Server 2016 Standard Edition	2 / 56 / 112	10/23/19
6	Lenovo	Lenovo ThinkSystem SR655	6,717	99.99 USD	NR	12/31/19	Microsoft SQL Server 2017 Enterprise Edition	Microsoft Windows Server 2016 Standard Edition	1 / 64 / 128	08/02/19
7	Lenovo	Lenovo ThinkSystem SR665	2,579	68.62 USD	NR	08/17/21	Microsoft SQL Server 2019 Enterprise Edition	Microsoft Windows Server 2019 Standard Edition	2 / 16 / 32	08/12/21

'NR' in the Watts/tpsE column indicates that no energy data was reported for that benchmark.

Example of current approach to assess resilience: RMI



Example of current approach to assess resilience: RMI



- **34 groups** of resilience indicators
- Structured bottom up approach
- Attributes calculated using decision analysis and MAUT (multi-attribute utility theory)

Henrique Madeira, DEI-FCTUC, 2021

Key elements of future resilience CI benchmarks

- **Abstraction**: to condense the high complexity of the CIs into a carefully designed abstract description that includes the essential elements of the target CI, allowing easy, reliable, and meaningful measurements of the key indicators.

- **Compact set of indicators**: to use a small set of numeric indicators (one metric, whenever possible) to express the result of the assessment in a simple and easy to understand format. Refinement in more detailed indicators for thorough analysis is also inline with the benchmarking approach.

- **Properties**: to design the assessment method seeking for simplicity while making sure that the key elements of the method and the resulting measurements fulfil a set of properties to be considered valid and meaningful.

Henrique Madeira, DEI-FCTUC, 2021

Benchmark properties

- **Representativeness** - measurements must represent reality of actual systems
- **Repeatability** - guarantees statistically equivalent results when the measurements are taken more than once in the same circumstances
- **Reproducibility** - assures that another party obtains statistically equivalent results
- **Portability** - assures the method can be consistently used across different types of target systems
- **Non-intrusiveness** - the assessment method must not change the system under benchmark
- **Scalability** - can evaluate systems of different sizes
- **Effort moderation** - the time and cost need to obtain the measurements must be acceptable for the users.

Possible benchmark metrics

- **IRI**, a single global **Infrastructure Resilience Indicator** to provide a quick and easy to understand view for CI managers, policy makers, regulators entities, and public in general
- An indicator breakdown to drill-down the resilience indicator structure for detailed and focused technical analysis.
- **IRI**, a first level of **three macro indicators**:
  - **Protection**: indicates how effectively the infrastructure is protected.
  - **Recovery**: indicates how fast the infrastructure can recover in case of hazard or attack.
  - **Protection cost**: indicates the cost of infrastructure protection in terms of efficiency-security trade-off.

Calculation of indicators

- **Qualitative analysis**: identification of threats, vulnerabilities, potential impact (considering different scopes for the impact), risk analysis, and other relevant elements that can be identified (rather than quantified) using table based and checklist screening techniques.

- **Experimental verification and measurement**: identification of vulnerabilities and interdependencies, robustness measurement of key infrastructure elements (technical and human), measurement of hazard impact, among others.

- **Modelling**: provision of a higher level vision to integrate the constituent elements of the assessment in a coherent and consistent way, analysis and assessment and a probabilistic oriented forecast of the likely and expected resiliency.

Henrique Madeira, DEI-FCTUC, 2021

CI resilience benchmark users

- Who is going to use the resilience benchmarks for CI
  - Infrastructure managers
  - Engineers of critical infrastructures
  - Public safety and civil protection agencies
  - Researchers

Conclusion

- Benchmarks allow to compare alternative or competitive solutions according to one or several attributes → **The end goal is to induce progress**
- Benchmarks must be simple to understand; compact set of resilience indicators and a neat scale
- Use drastic simplification (abstraction) but keep the essential elements that assure fair comparisons and progress
- Are highly focused on very specific domains or types of target systems
- Benchmark properties are gatekeepers to validate benchmarks
- **Are resilience benchmarks for CIIs and CIs possible?**